A Modelling Study to examine threat assessment algorithms for Bicycle-Automatic Vehicle Interactions

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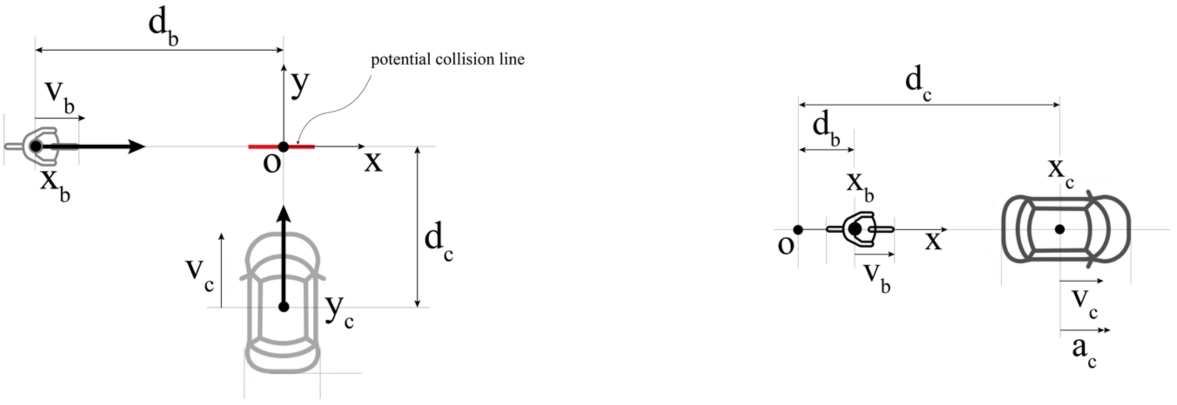
1 INTRODUCTION

Falls are responsible for a large proportion of serious injuries and deaths among cyclists [1]. A common fall scenario is loss of balance during an emergency braking maneuver to avoid another vehicle [2-4]. Automated Vehicles (AV) have the potential to prevent these critical scenarios between bicycle and cars. However, current Threat Assessment Algorithms (TAA) used by AVs to decide upon safe gaps and decelerations when interacting with cyclists only consider collision avoidance [REF] and do not consider bicycle specific balance related constraints. Our hypothesis is that the existing TAA can therefore not reliably predict the threat of a fall and misjudge unsafe interactions.

The goal of this study is to theoretically test this hypothesis with a simple Newtonian mechanics model that calculates the performance of two existing TAAs in four critical scenarios for two road conditions. The four scenarios are: (1) a crossing scenario and a bicycle following lead car scenario in which the car either (2) suddenly braked, (3) halted or (4) accelerated from standstill. These scenarios have been identified as common scenarios in bicycle-car conflict studies [8-11] and are illustrated in Figure 1. The two existing TAAs are Time-to-Collision (TTC) and Headway (H). These TAAs are commonly used by AVs in the four critical scenarios that will be modelled [REF]. The two road conditions are a flat dry road and a downhill wet road, for which the latter are the worst-case conditions to avoid loss of balance during emergency braking [12]. We have chosen to first test our hypothesis with a simple model to determine whether it is worth the investment to collect data about critical bicycle-car interactions, which is expensive, complex, time-consuming and have ethical dilemmas [REF].

2 APPROACH

The Newtonian mechanics-based model can calculate for a set of interactions (varying combinations of initial distances d_b, and d_c, and initial speeds v_b and v_c, see Figure 1) whether a fall of the cyclist or collision between the vehicles occurred. For the same range of interactions we determined whether the TTC or H predicted the interaction was safe or unsafe. The predictive performance of the TTC and H was defined as the proportion of misclassifications of unsafe interactions.



(a) *(b)*

Figure 1:Top view of two types of bicycle-car interaction: (a) A bicycle-car crossing interaction with the location of the bicycle center, x_b, and the car center, y_c, in reference to the origin O of the global fixed coordinate system. The thick red horizontal line at the origin is the potential collision line. The initial distances from the origin are d_b for the bicycle and d_c for the car. The initial velocities are v_b for the bicycle and v_c for the car. (b) A bicycle following lead car scenarios with the location of the bicycle center, x_b, and the car center, x_c, in reference to the origin O of the global fixed coordinate system. The initial distances from the origin are d_b for the bicycle and d_c for the car. The initial velocities are v_b for the bicycle and v_c for the car. The constant acceleration of the car is a_c, which is negative for the suddenly braking car scenario, zero for the halted car scenario and positive for the accelerating car scenario.

3 RESULTS

The proportions of misclassifications of all scenarios, TAAs and road conditions are numerically presented in Table 1 and are visualized in Figure 2 for a crossing scenario on a flat dry road and a TTC threshold of 1.2 seconds. The results show that for a crossing scenario on a flat dry road a TTC threshold of 1.0 and 1.2 seconds misclassified respectively 34% and 9% of the unsafe interactions as safe. This proportion was 22% for a bicycle following a suddenly braking car and a TTC threshold of 2.0 seconds, and 1% for a halting car. For H, the misclassifications were respectively 0% and 4% in these scenarios. For downhill riding on a wet road, the proportion of misclassifications increased by at least 15%. In contrast, for the accelerating car scenarios, the classifications were too conservative by misclassifying 17 to 21% of safe interactions as unsafe.

Table 1: Proportions of misclassifications in % between the Newtonian mechanics model and TTC or H for the four critical scenarios and for a flat dry road and a downhill wet road.

	flat dry road		downhill wet road	
model	safe	**unsafe**	safe	**unsafe**
TTC	unsafe	**safe**	unsafe	**safe**
crossing scenario				
TTC threshold: 1.0 s	0%	**34%**	0%	**35%**
TTC threshold: 1.2 s	0%	**9%**	0%	**11%**
bicycle following suddenly braking car scenario				
TTC threshold: 2.0 s	8%	**22%**	0%	**51%**
H threshold: 1.8 s	19%	**0%**	0%	**17%**
bicycle following halted car scenario				
TTC threshold: 2.0 s	3%	**1%**	0%	**16%**
H threshold: 1.8 s	1%	**4%**	0%	**20%**
bicycle following car accelerating from standstill				
TTC threshold: 2.0 s	21%	**0%**	14%	**0%**
H threshold: 1.8 s	17%	**0%**	10%	**0%**

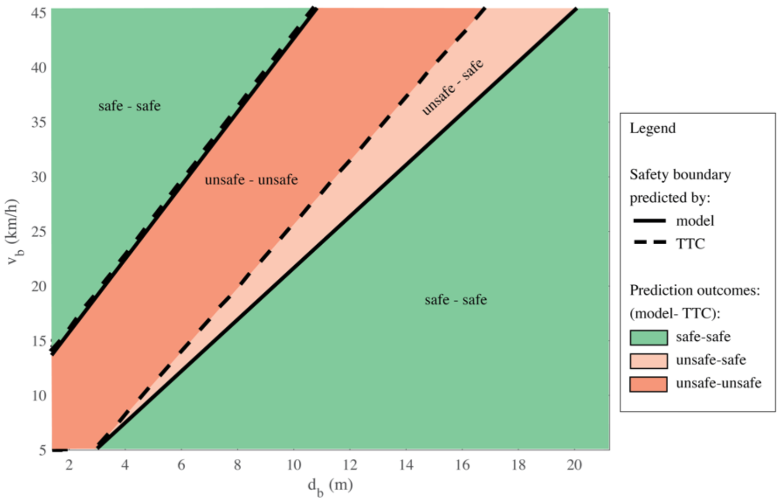


Figure 5. Comparison of misclassifications between the Newtonian mechanics-based model and a TTC with a safety threshold of 1.2 s for the bicycle-car crossing scenario and a dry flat level road. The set of interactions considered are all combinations for an initial position of the bicycle (d_b) between 2 to 21 m and an initial velocity of the bicycle (v_b) between 5 to 45 km/h. All other parameters were kept constant. The green safe-safe area and dark red unsafe-unsafe area are combinations where the prediction of the TTC agrees with the outcome of the model, whereas the light red unsafe-safe area are combinations where the TTC predicts a safe but the model outcome is an unsafe interaction. The percentage as a fraction of the square area are: safe-safe 66%, unsafe-unsafe 25%, unsafe-safe 9% (see Table 1).

4 CONCLUSIONS

These findings illustrate that TAAs for AVs that ignore falls may take decisions that either put cyclists at a high risk of injuries or are detrimental for traffic flow. Further study and data about critical bicycle-car interactions and bicycle emergency braking is needed to develop adequate TAAs that can reliably predict falls and are safe for cyclists.

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